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An approach to modelling the effects of network centricity in maritime warfare

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TTCP MAR AG-1 — Quantitative modelling of NCW

- Inaugural meeting: Adelaide, October 2001
- First workshop: Vancouver, April 2002
- Second workshop: Auckland, October 2002 (plus second Annual Meeting)
- Third workshop: Newport, April 2003
- VTCs between each meeting

(Australian National Leader for AG-1: Chris Davis)

Outline

- TACSITS adopted by AG-1
- Tactical-level model of maritime interception operations (MIO) using queueing theory
- Concept of analysis — two-stage
- Plans for stage 2:
  - levels of networking
  - developing the second stage for MIO

TACSITS and hypotheses

1: MIO. Network-enabled collaborative planning/re-planning increases the probability of intercepting a contraband vessel.

2: ASW. A network-enabled common tactical picture (CTP) reduces the false contact loading of prosecuting ASW units.

3: Swarm attack. A network-enabled CTP and distributed sensor-to-shooter network reduces the number of Red threat leakers against Blue platforms.

4: Focused logistics.

5: Anti-air warfare.

6: Carrier battlegroup operations.

7: Mine warfare.

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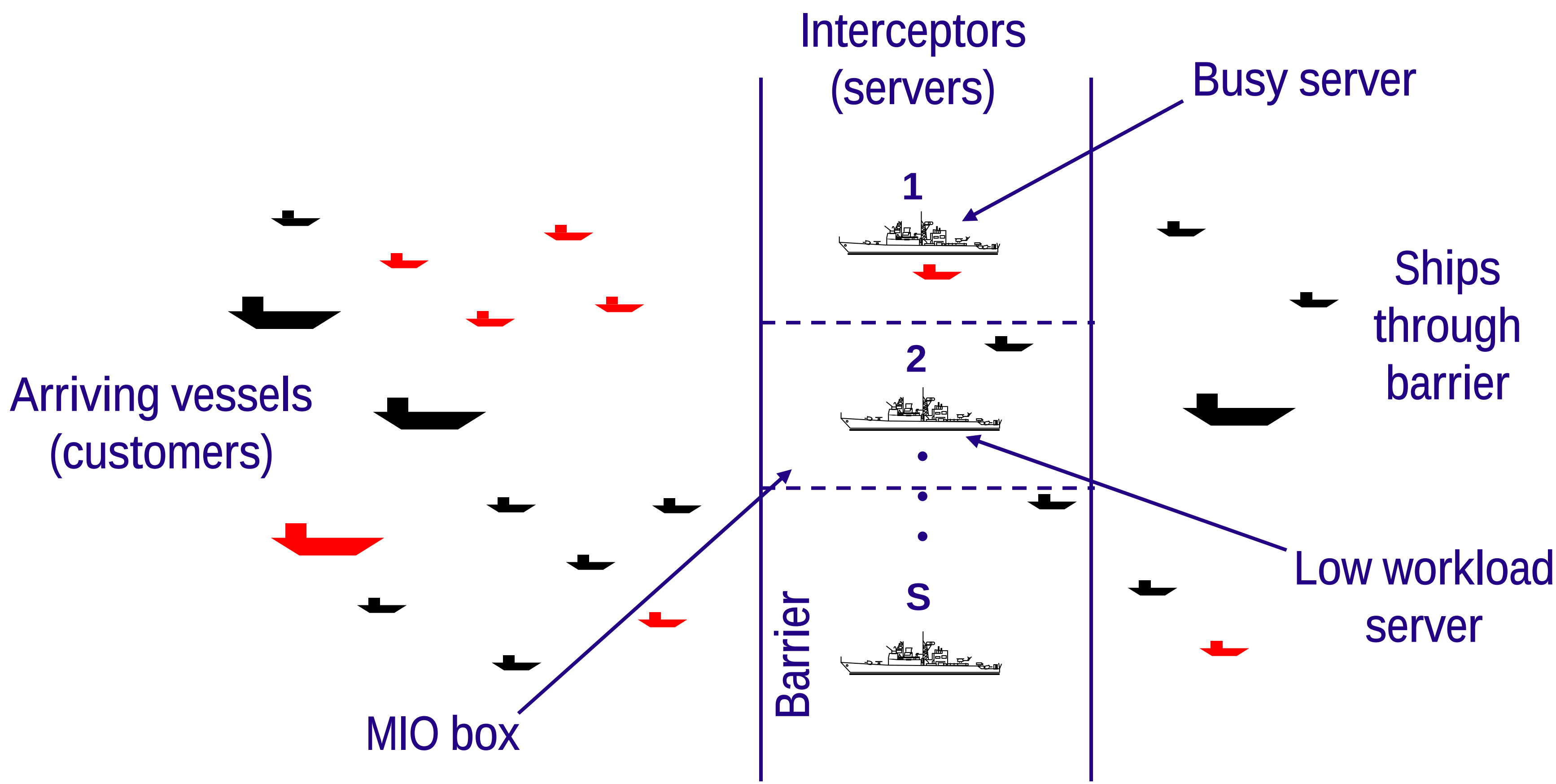
Maritime interception — a coastline of recent interest

Platform-Centric Case — Interceptors have an area of responsibility



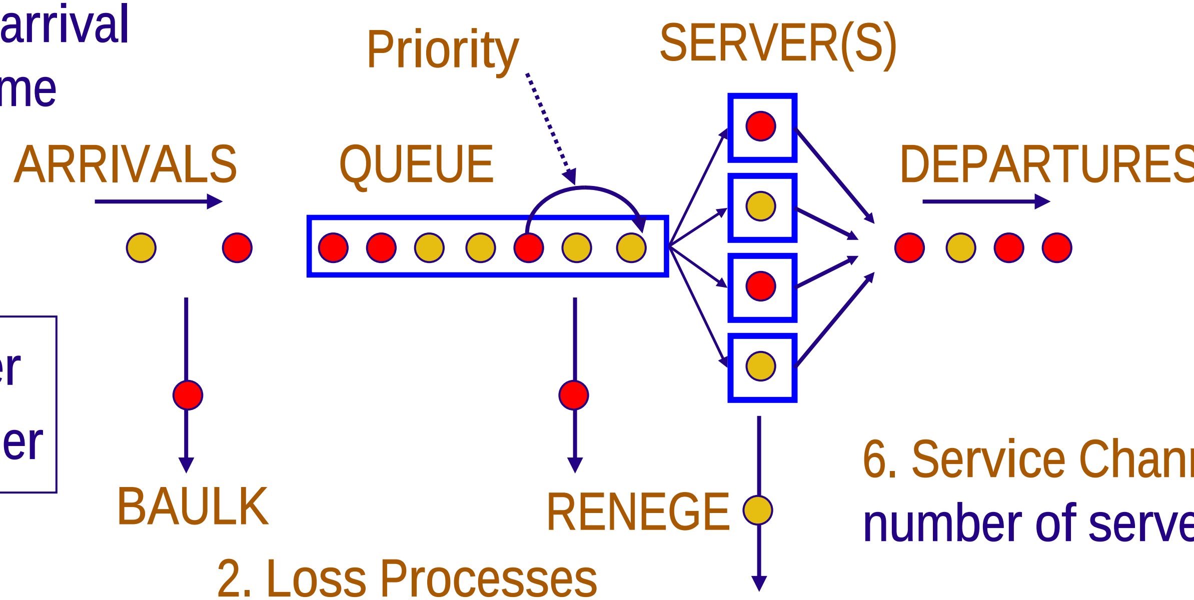
Queueing Systems — describe demand for service

3. System Capacity — maximum length of the queue plus number of servers

4. Queue Discipline — which customer is next served

5. Service Pattern — service rate or service time

1. Arrival Pattern — arrival rate or interarrival time



- genuine customer
- mistaken customer

2. Loss Processes

6. Service Channels — number of servers

MIO attributes ⇔ queueing-theory quantities

Queueing-theory quantity	MIO attribute
customer	vessel of interest (VOI)
server	interception force element
service	all the steps in dealing with a VOI
queue discipline	are waiting VOIs prioritised?
reneging	VOI transits interception region and so escapes
baulking	VOI chooses not to enter interception region

Parameters and outputs

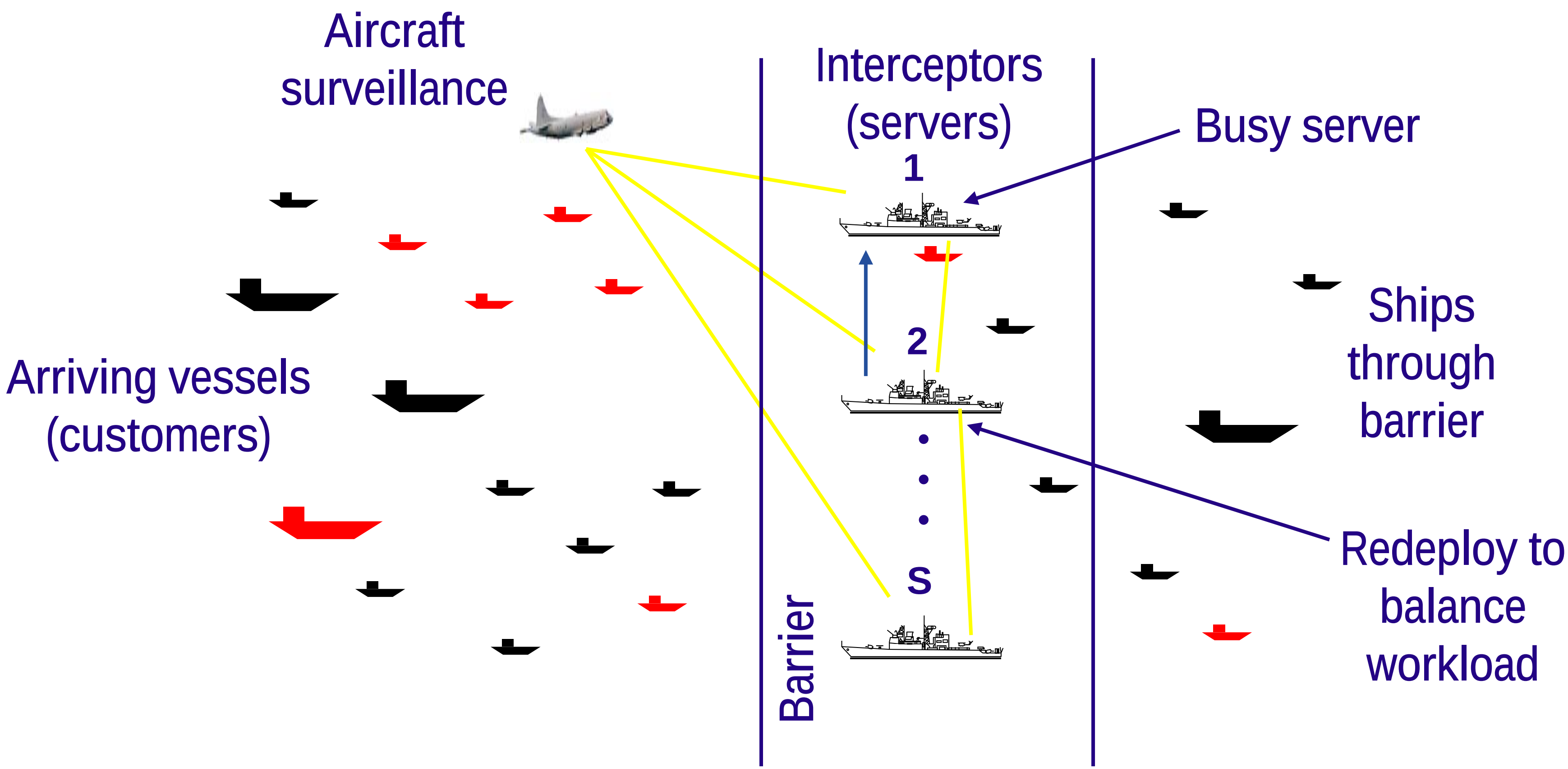
Typical parameters:

- Mean arrival rate: 25 vessels per day
- Mean service time: 4.0 h
- Mean renege time: 1.0 h

Outputs

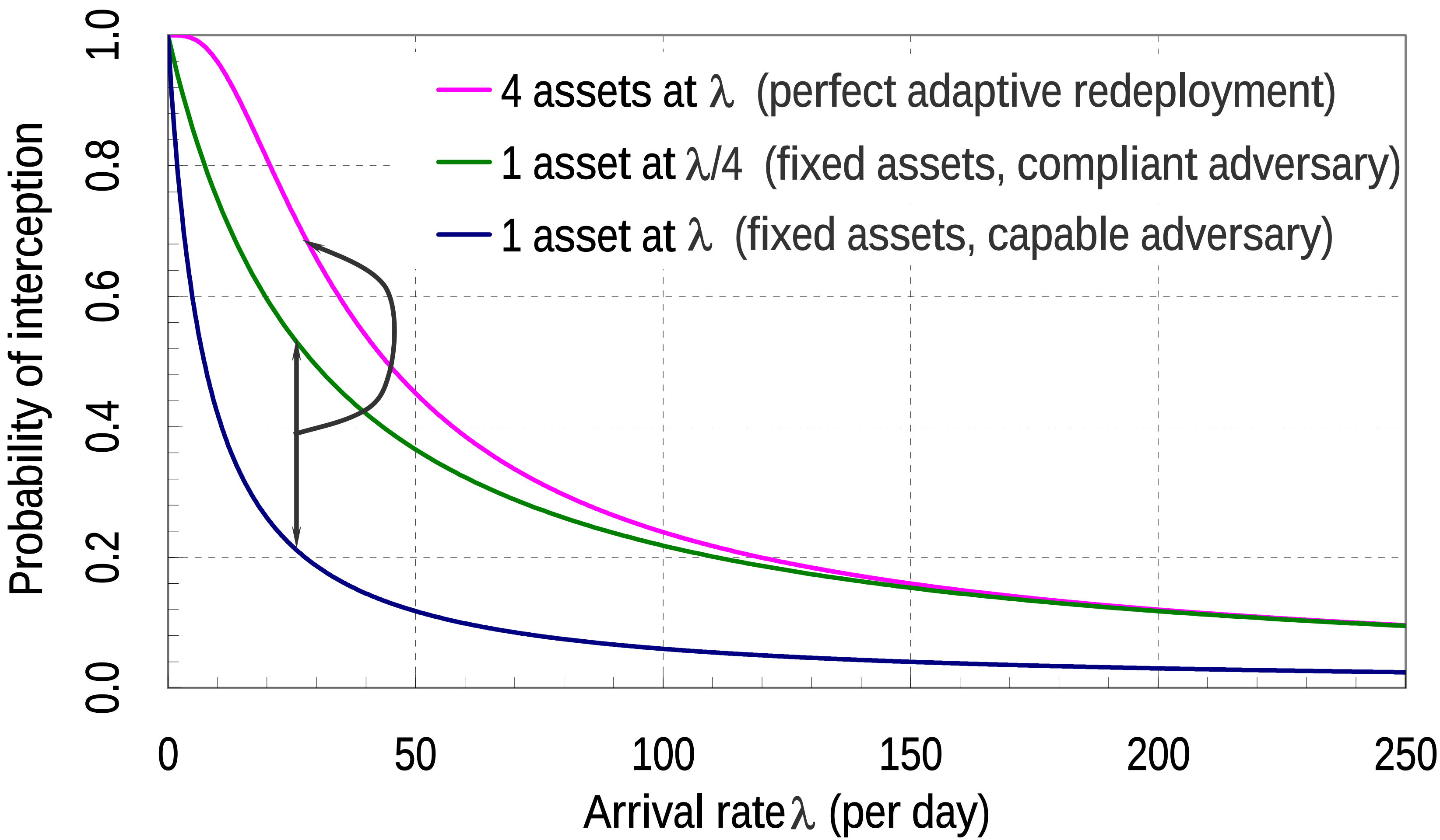
- Probability of acquiring service:
  Fraction of customers that complete service
  $\equiv$ probability of interception
- Mean waiting time in the queue

Networking Enables Adaptive Redeployment



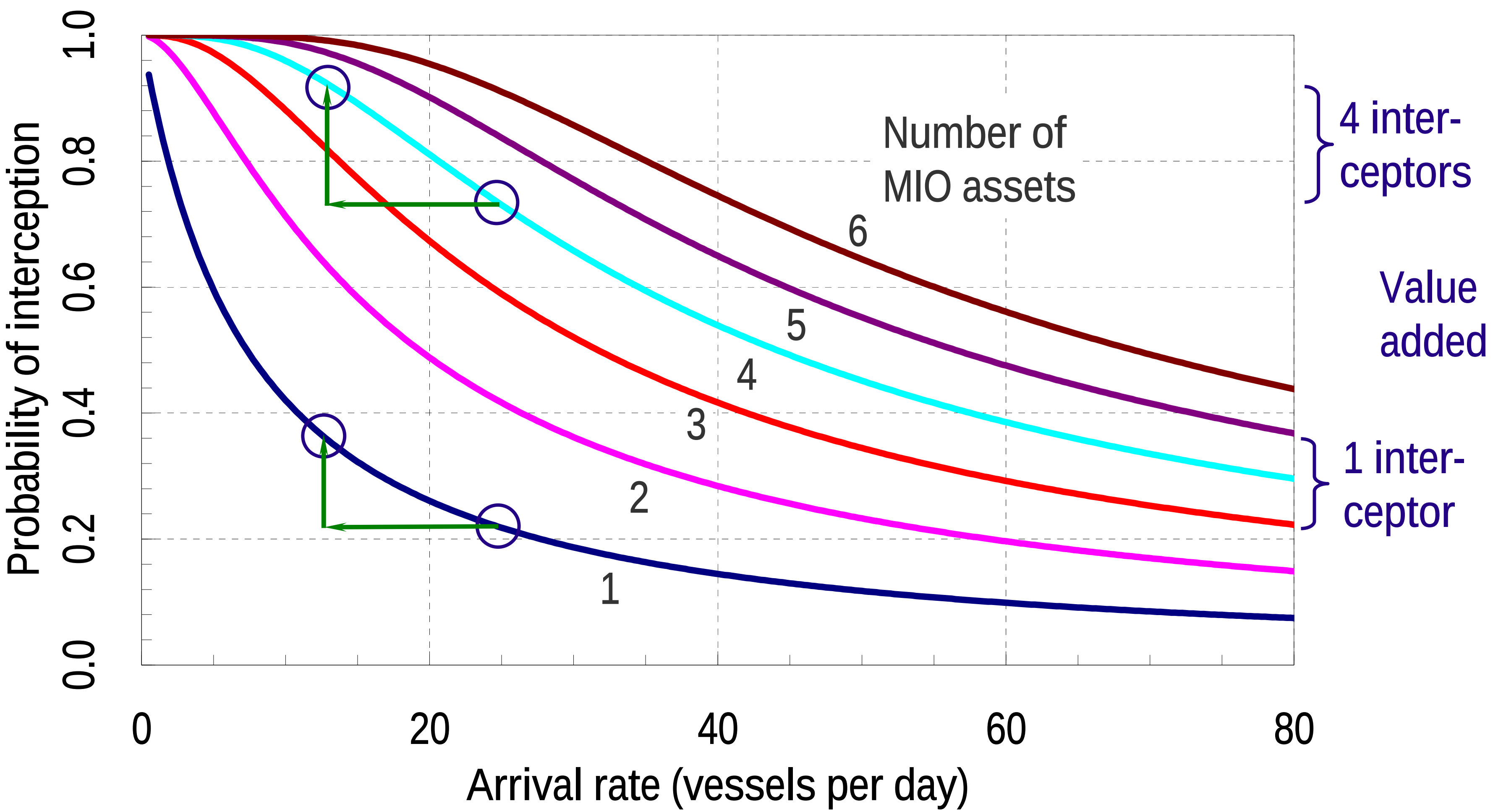
Adaptive redeployment aims to equalise the workload of the interceptors.

Effect of adaptive redeployment



Mean service time = 4.0 h; Mean time to transit MIO box (renege time) = 1.0 hr

Effect of increased classification performance



Assume a 50% reduction in arrival rate due to improved classification
(mean service time = 4 h, mean renege time = 1 h)

Summary so far

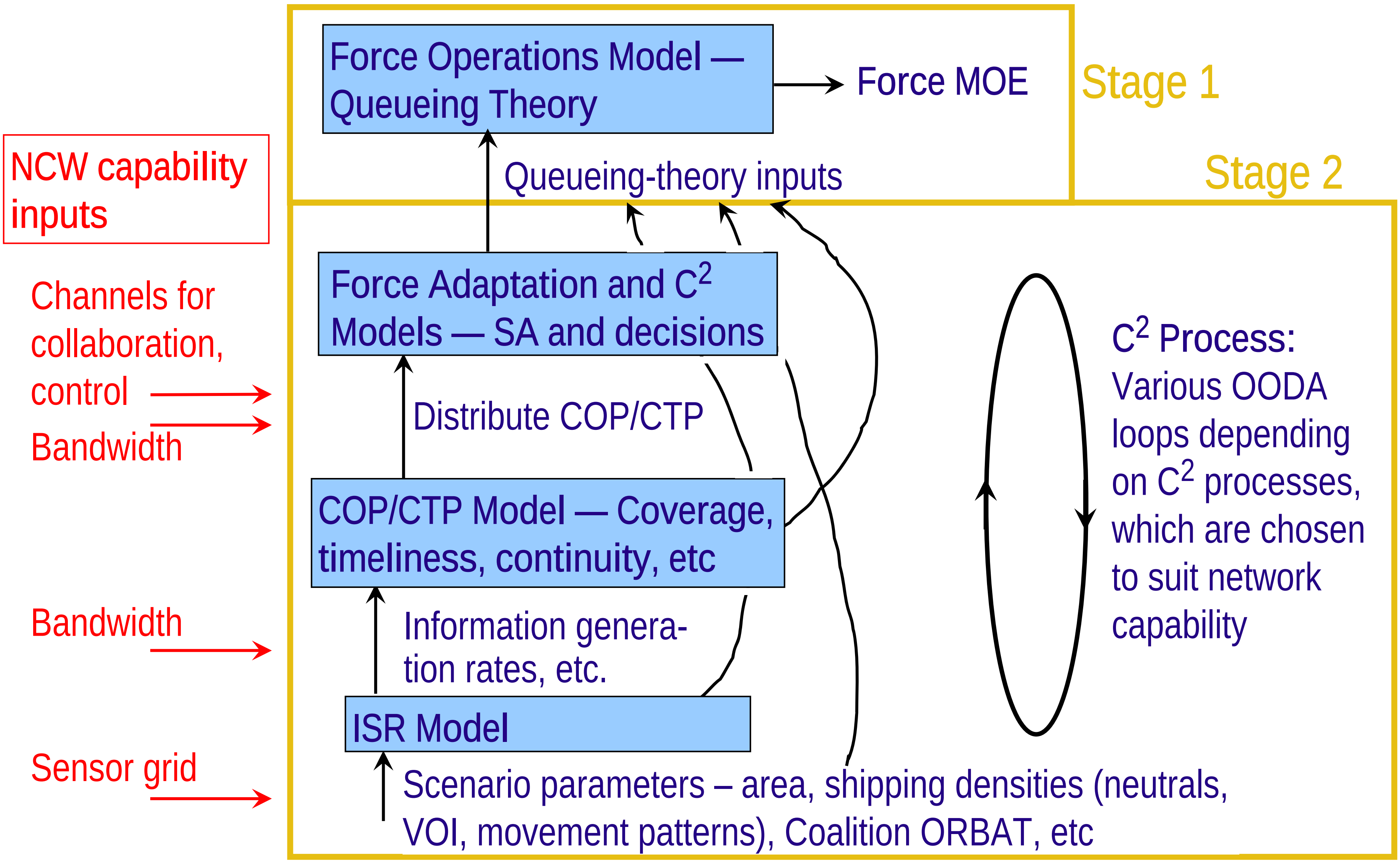
Improved information flow improves:

- adaptive redeployment in MIO
- classification of incoming vessels in MIO

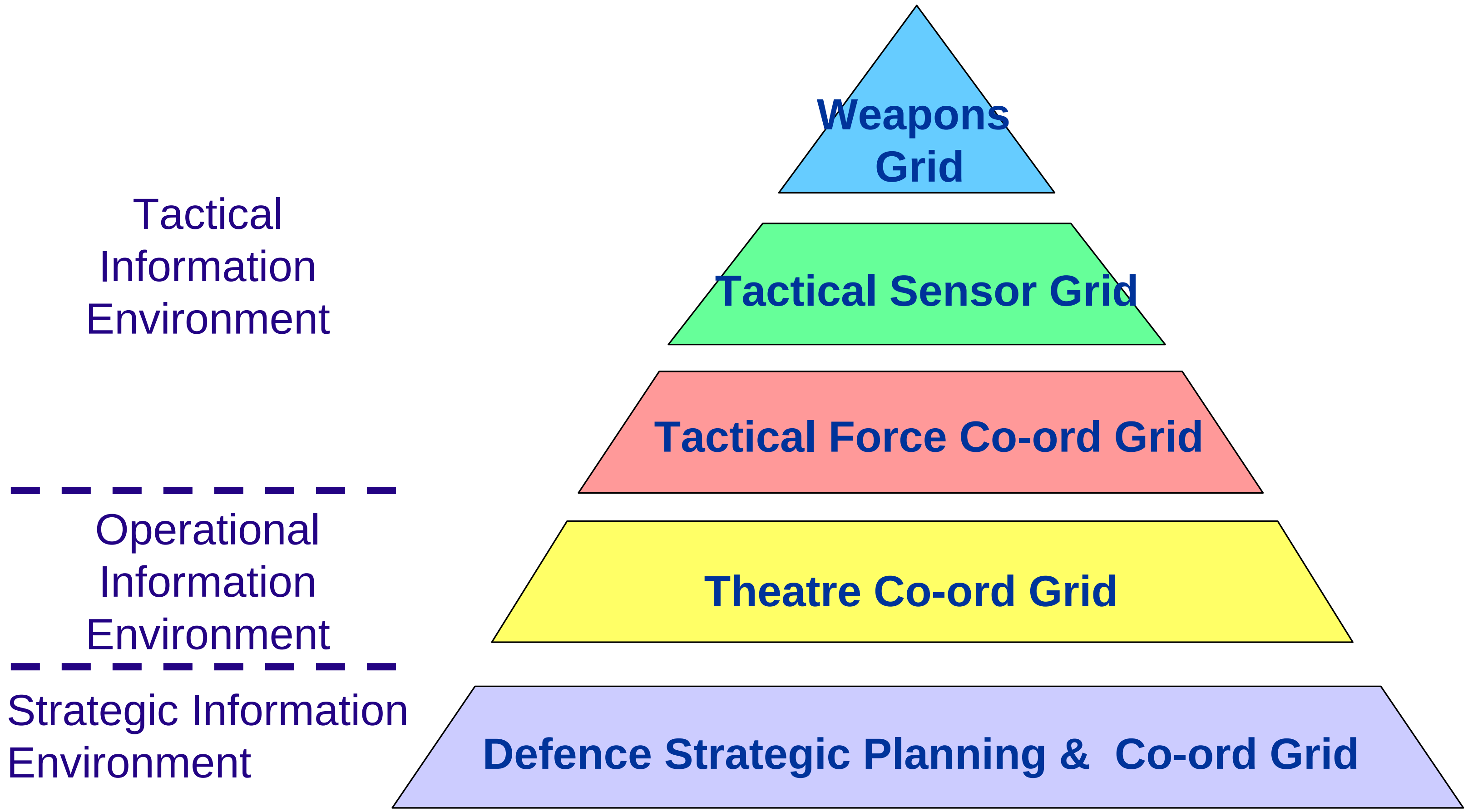
Queueing theory gives the quantitative gain in MOE

But — how much networking is required in each case?

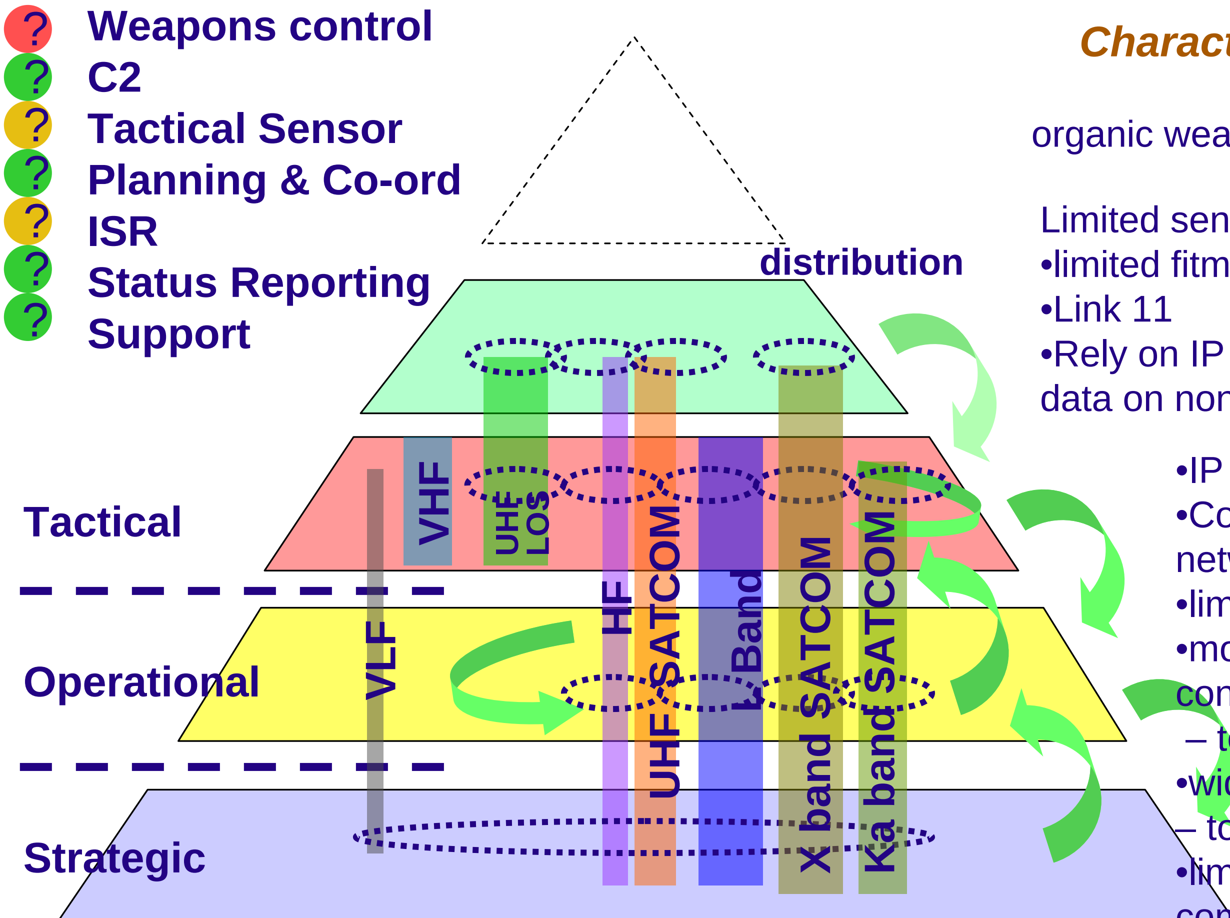
Two-stage analysis (from Chris Davis)



Notional network architecture (from Meredith Hue)



Medium Level of Networked Capability



Characterised by

organic weapon control only

Limited sensor nets to share sensor data
•limited fitment of Link 16
•Link 11
•Rely on IP networks to share sensor data on non-link platforms

•IP Networks to carry data traffic
•Cowan security enclave network connectivity,
•limited integrated voice/data,
•moderate wideband connectivity BLOS
– to some MFUs only,
•wideband LOS
– to some MFUs only
•limited interconnection between comms bearers
•multiple applications per bearer
•Supporting organisational structure, processes, procedures
•Supporting tactics, doctrine, procedures

Moderate interoperability, connectivity, quality, quantity

• service access, message format, waveform, RF spectrum compatibility
• managed quality of service for traffic flow

Proposed stage-2 analysis — a simulation

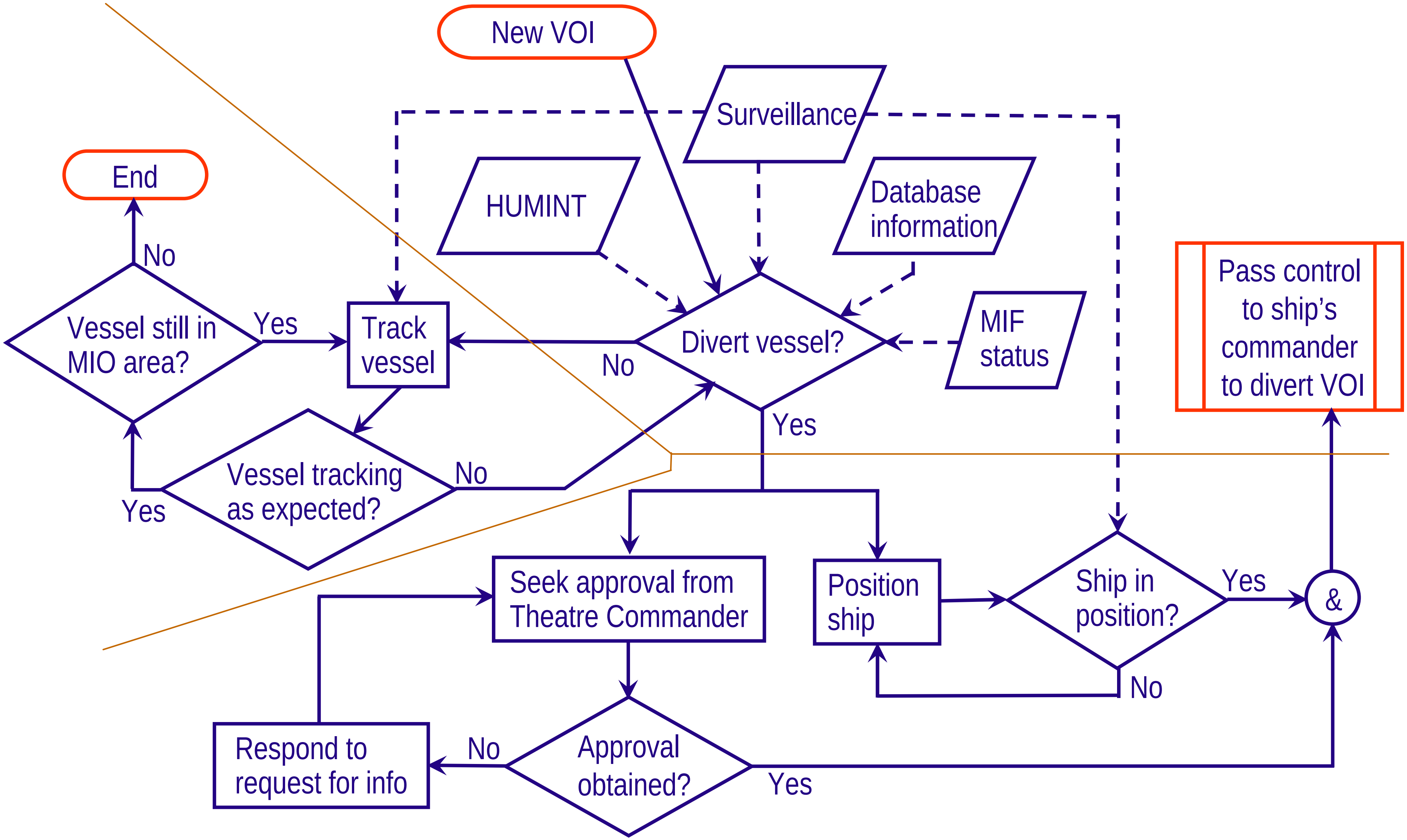
- Two-component model:
  - Physical model — dispositions of entities in the area of operations
  - Cognitive model — how the MIF commander sees it

- Desired output:
  - Distribution of C^2 process times (part of the service-time distribution) as a function of networking capability
  - Impact of adaptive redeployment on the effective number of servers in a MIO box

Participants in the Auckland Workshop

- Australia: Matthew Fewell, Ian Grivell
- Canada: Bob Burton, Mark Hazen (Chair)
- New Zealand: Chris Philp
- UK: Peter Marland
- USA: Ralph Klingbeil, Keith Sullivan

MIF Commander’s flow chart — a first attempt



Application to anti-submarine warfare

Steps in prosecuting a submarine

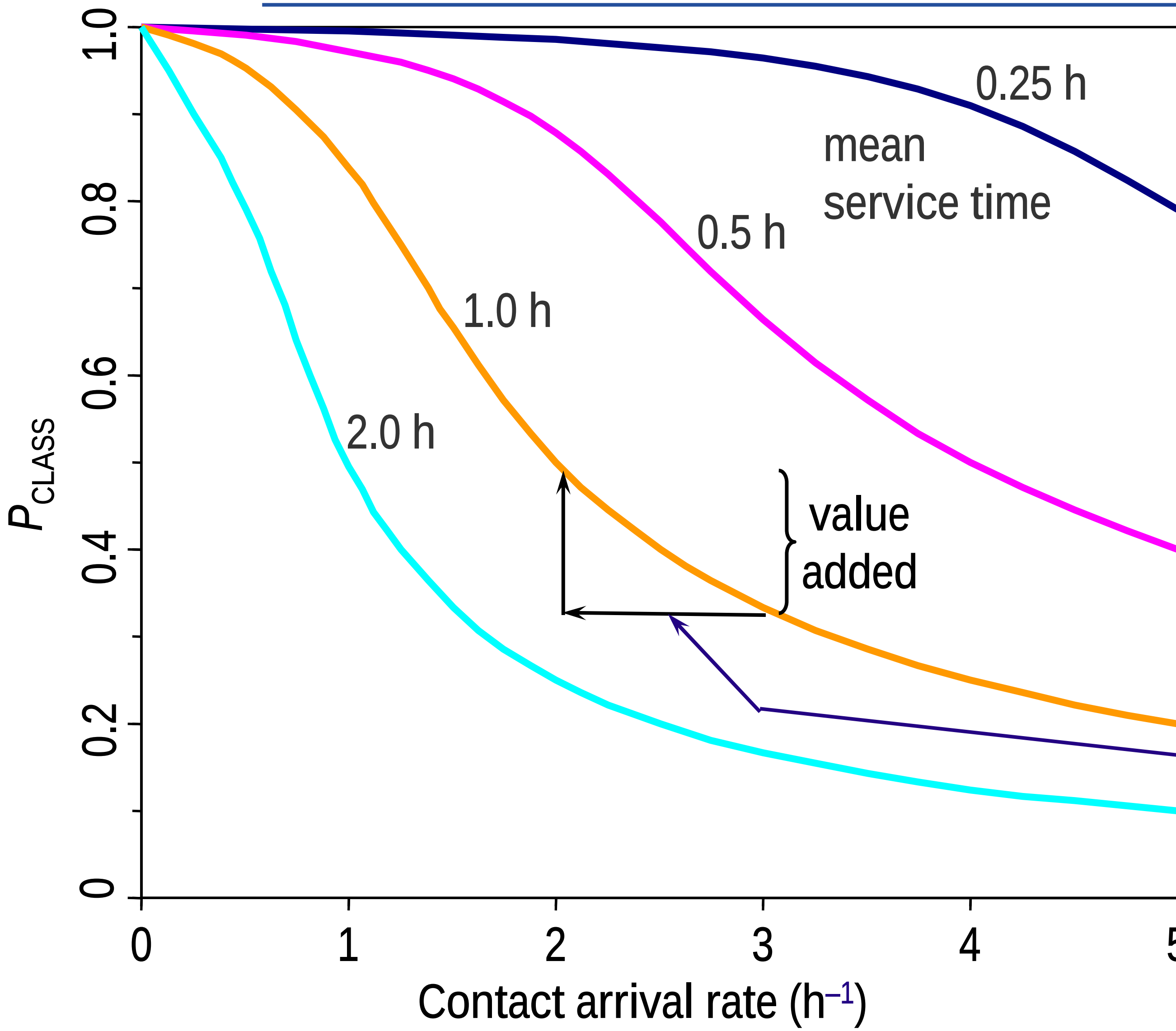
- detection and classification
- localisation
- target-motion analysis
- attack

Each step has characteristics of a queue

ASW classification attributes ⇔ QT quantities

Queueing-theory quantity	ASW classification attribute
customer	detected contacts
server	sonar operator
system capacity	max. no. of contacts that can be managed at any time
queue discipline	are waiting contacts prioritised?
reneging	contact is lost before classification is achieved
baulking	potential contact is below the detection threshold or system is already full

Effect of improved shared situational awareness



mean time to renege = 0.25 h,

1 classifier (server)

Improved shared situational awareness reduces the number of false contacts

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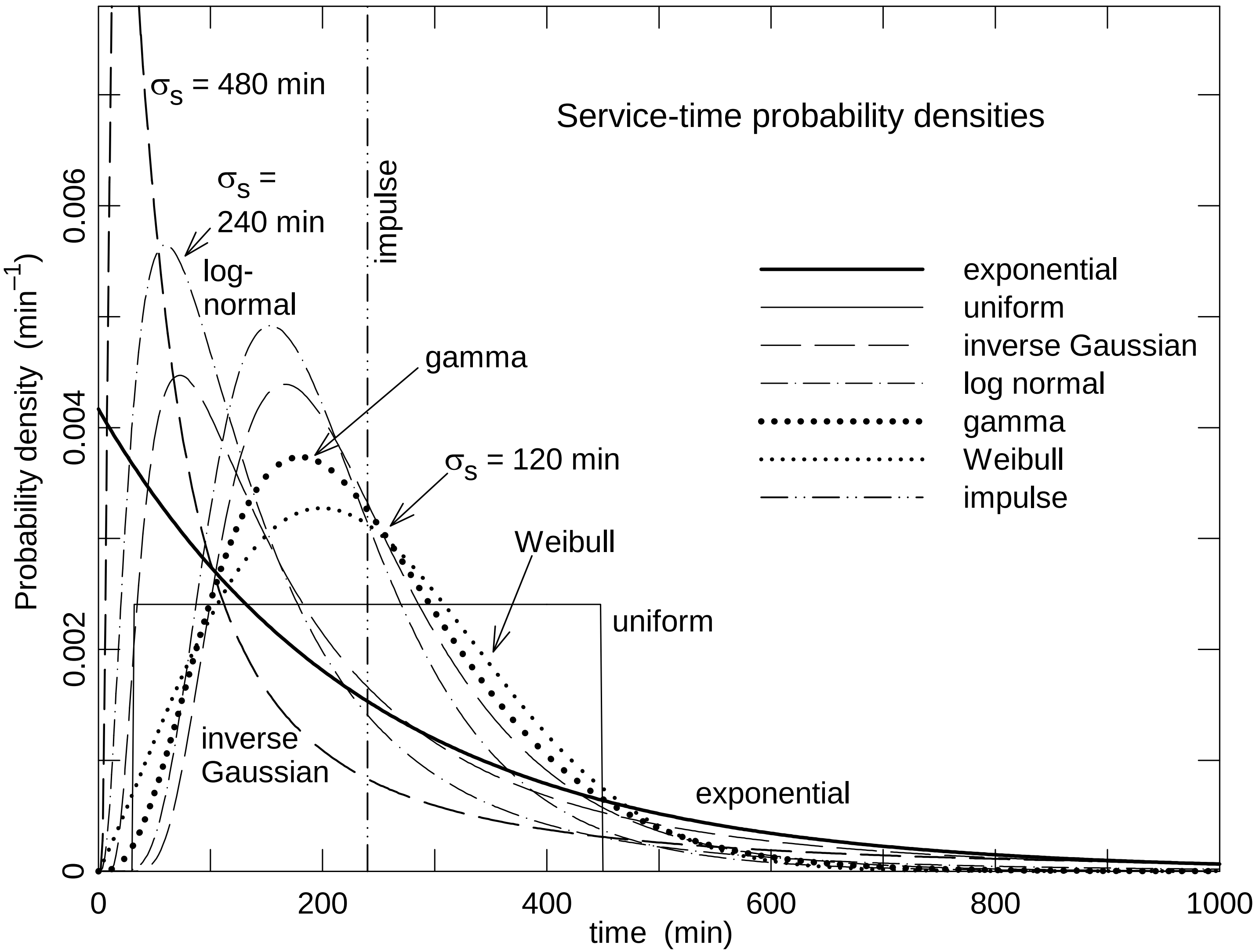
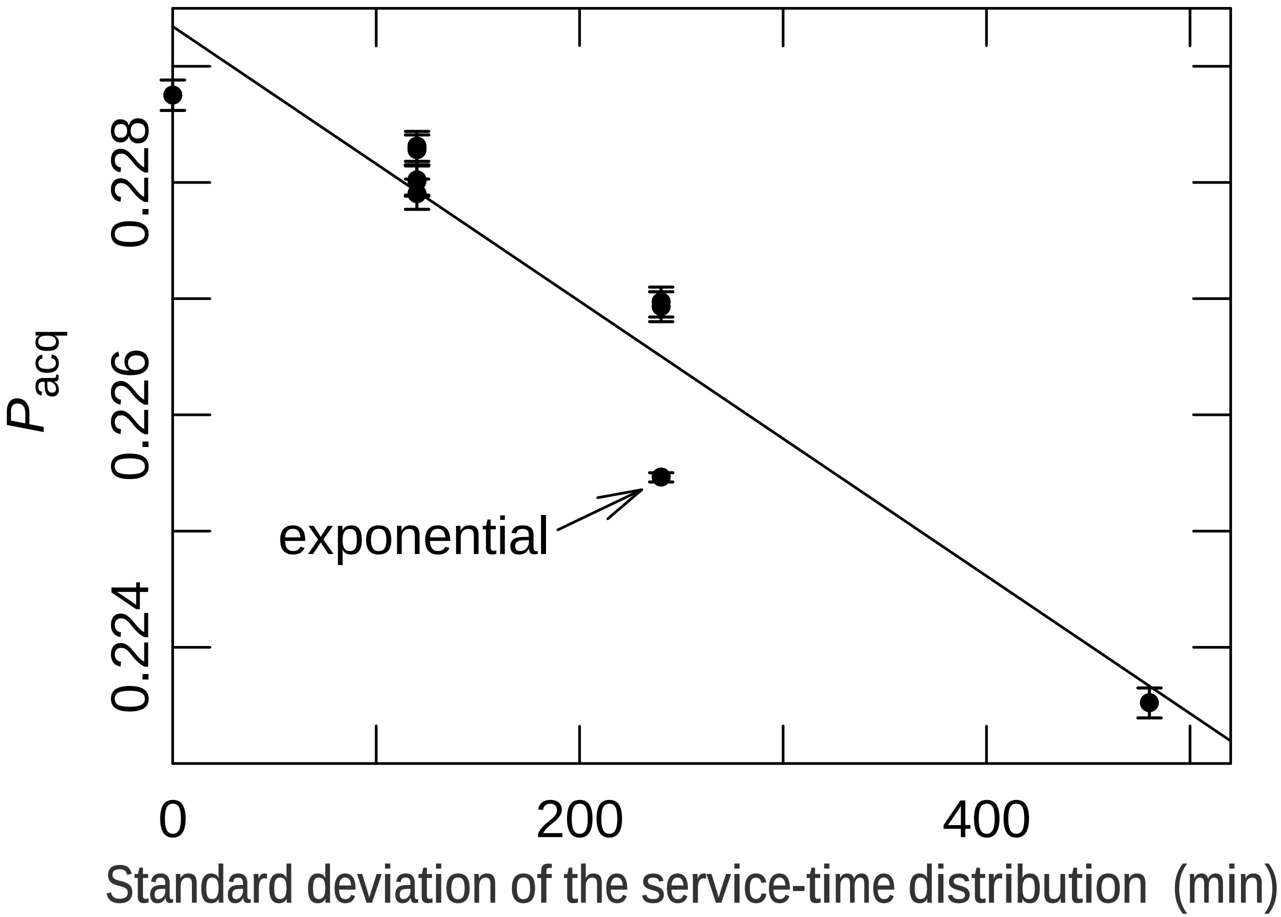
Range of service-time distributions explored



All have a mean of 240 min

Effect on probability of acquiring service



Mean service time = 240 min

Mean renege time = 60 min

Mean inter-arrival time = 60 min

1 server

The equations of queueing theory

$$
\begin{aligned}
P_n(t+\Delta t) = \\
& P_n(t) \quad (1-\lambda\Delta t)(1-\mu\Delta t) \\
& + P_{n+1}(t)\,(1-\lambda\Delta t) \quad \mu\Delta t \\
& + P_{n-1}(t) \quad \lambda\Delta t \quad (1-\mu\Delta t)
\end{aligned}
$$

(exponential probability distributions,
no reneging or baulking)